Discoloration of Ponderosa Pine on the San Juan National Forest, 1999-2001

Biological Evaluation R2-02-06

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Abstract: Since before 1999, a needle-cast epidemic has been building on the San Juan National Forest. Spring discoloration and subsequent defoliation were apparently more widespread and severe in 2001 than in previous years, leading to concern for potential mortality. The pathogen is *Davisomycella ponderosae*. It appears that unusual weather patterns in recent years, including the wet summer of 1999 and the very hot, dry growing season of 2000, contributed to the build-up of the epidemic and to the severity of the damage. Of many site and stand factors studied, slope position and aspect are related to the amount of damage. Basal area was positively, but not significantly, related to discoloration. The future of the epidemic depends on future weather patterns and infection requirements that are not well known. Some mortality may occur in more severely affected stands, particularly if the mountain pine beetle responds to stressed trees.

1. INTRODUCTION

In 1999, 2000 and 2001, ponderosa pine on the San Juan National Forest showed foliage discoloration that has apparently increased in severity each year. In this report, observations and data on the phenomenon are presented and possible causes are evaluated.

1.1 Background

1.1.1 1999

On April 30, 1999, Dave Crawford sent samples of discolored ponderosa pine needles to Forest Health Management, Gunnison Service Center. The sample was from the south end of the Pagosa Springs District, in the Valle Seco and Kenny Flats area. He indicated that on trees scattered in some stands over a widespread area, discoloration appeared on most of the 1998 needles. Discoloration was observed over the whole elevation range of ponderosa pine. The samples had a wide variety of lesions, spots, mottles, and bands that could not be associated with a particular disease. A few of the needles had long hysterothecia (fruiting bodies of needle-cast fungi), but they were immature and could not be identified.

1.1.2 2000

On June 29, 2000, Teresa Johnstone reported ponderosa pines looking very poor along Highway 145 near Stoner, CO and the West Fork of the Dolores River. Bill Jacobi, of Colorado State University, reported that he had seen discoloration in this area in previous years also, suggesting that the forest-wide epidemic may have begun in this area. In July, Tom Eager collected samples from Road 204, north of Durango, and submitted them to the Colorado State University Identification and Diagnostic Service. Although no sexual fruiting was present, the pathogen *Davisomycella* sp. was identified. On August 23, 2000, Dave Crawford reported discoloration from Dolores to Pagosa Springs, noting that the new foliage tended to mask it but it was still there.

1.1.3 2001

The problem was more severe in 2001. Dave Crawford, Bob Frye and Steve Hartvigsen reported widespread, though variable discoloration in May. Yellowing and browning were seen in multiple years' needles, but especially in complements of 1999 and before. Needle loss in those complements was seen also. In some cases 2000 needles were also affected. So severe was the condition that these observers suggested that some tree mortality may result.

Areas noted as especially severe included the Pine River valley north of Bayfield, (especially approaching Vallecito), from the west side of Yellowjacket Pass all the way to the Kenney Flats/Valle Seco area southeast of Pagosa Springs, and Willow Draw.

2. METHODS AND MATERIALS

2.1 Preliminary observations, 2001

On May 30-31, 2001, we travelled through the San Juan National Forest to make general observations of the condition. We collected data west of Wolf Creek Pass near West Fork Campground and East Fork Campground, south of Pagosa Springs at 8-Mile Mesa, northwest of Pagosa Springs along Piedra Road, along Fossett Gulch Road west of Chimney Rock, along Road 135 north of Yellowjacket Pass, at Vallecito Lake Dam, and along Road 576 12 miles north of Durango.

2.2 Formal Field Sampling

Based on the results of these observations, Steve Hartvigsen arranged for two people to do a more intensive survey using methods based on our suggestions. The suggested protocol is in Appendix A. Thirty-six sites were studied, arbitrarily scattered near forest roads across the Forest. Sampling was done during late June and early July of 2001.

An increment core was collected from one of the sample trees in most sites. These were used to determine if there had been a recent decrease in radial growth in heavily impacted sites. Using a dissecting microscope, we measured the total ring width of the last 5 years and the last 20 years, starting from the 2000/2001 winter. In the few cases where the core contained less than 20 years, the measured length was expanded to 20 years. Growth decline was calculated as the percentage decrease in radial growth ($mm \cdot yr^{-1}$) between the first 15 years and the last 5 years of the 20-year period.

Needle retention was examined as two variables. First, number of years of needle retention was represented for each tree by the number of years with 50% or more needle retention (ignoring nee-

1.1.1 2000

[illegible] In July, Tom [illegible] collected samples [illegible] submitted them to the Colorado State University [illegible]

1.1.2 2001

[illegible] following and [illegible] May. [illegible] 1999 and [illegible] also affected. [illegible]

[illegible] Pine River valley [illegible] Vallecito [illegible] Pagosa Springs, and [illegible]

2. [illegible] AND METHODS

2.1 [illegible] 2001

[illegible] Pagosa Springs [illegible] Chimney Rock, along Road [illegible] Vallecito Lake Dam, and along Road 576 12 miles north of Durango.

2.2 Vallecito Field Sampling

Based on the results of these observations, [illegible] The suggested protocol is [illegible] Forest [illegible] during late June [illegible] 2001.

[illegible] collected from [illegible] radial growth [illegible] years [illegible]

[illegible]

dles produced in 2001, the year of observation). Needles produced in 2000 were considered one-year needles and so on to 1996 (five years needle retention). In addition, a defoliation index was calculated to provide a single defoliation rating for each site. Adding the three trees sampled at each site and the past five years for which percent needle retention was recorded, the maximum possible percent retention for a site totals 1500. The actual total retention was subtracted from 1500 to represent defoliation. Resulting values ranged from 645 (lowest defoliation) to 1300 (highest defoliation).

Discoloration index was calculated as the sum of percent discoloration estimates for all five years of needle complements for the three sample trees. Percent discoloration was only estimated for needles present, and the value was considered 0 when no needles were present for a year. Discoloration index ranged from 20 to 240 for the 36 sites.

To perform statistics on aspect, angular mean was calculated for groups of sites using the spatial statistics software, Crimestat (Levine 1999). Mean angle was weighted by percent slope in order to give more weight to aspect values that are associated with steeper slopes.

Correlations among continuous variables were examined in a correlation matrix. Pairwise deletion was used for missing values. Significant difference of correlation coefficients from 0 was tested with Fischer's r to z.

3. RESULTS

3.1 Preliminary Observations

In the stands that we visited for preliminary observations (Table 1), 95-100% of the trees had some discoloration and 90-100% of the shoots in those trees had some discoloration. Discoloration was evident throughout the trees, with no apparent directional or vertical trend in discoloration within trees (Fig. 1).

Figure 1. Discoloration of ponderosa pine along U.S. Highway 160 near Yellowjacket Pass, 31 May 2001, and a close-up of fruiting of *Davisomycella ponderosae* (inset).

At the sites we visited, some of the discolored needles had fruiting of a needle-cast fungus (Fig. 1, inset). In the laboratory this was identified as *Davisomycella ponderosae* (Staley) Dubin & Staley. John Staley, who described this species in 1964, later examined our specimens and confirmed the identification.

Table 1. Summary of preliminary observations at 8 sites in late May 2001.

	1998 foliage	1999 foliage	2000 foliage	Other symptom	Needle cast
West Fork CG	Most missing, rest discolored	Most missing, rest discolored	Some discolored	Symptoms highly varied	Few with hysterothecia
East Fork CG	Missing on some trees, ~80% discolored where present	Missing on some trees, ~80% discolored where present	Tips orange	Grey bands, beyond which needles are dead and straw-colored. SW white pines carrying 4+ years but some older needles are orangey.	Some concolorous hysterothecia seen.
8-Mile Mesa	Missing	Strongly discolored	Somewhat discolored, not fully elongated	Thin crowns.	Hysterothecia on 1999 needles.
Piedra Road	Missing or discolored	Missing or discolored	Some discoloration or missing, not fully elongated	Thin crowns. Affected needles are uniformly brown and dehiscing.	Few black hysterothecia.
Fossett Gulch Rd.	Many trees missing or orange	Many trees missing or orange	OK	Open, small trees have heavy sawfly defoliation.	Black sinuous hysterothecia relatively common.
Road 135	Mostly missing	Some trees missing 1999	Few dead, some did not fully elongate		Hysterothecia fairly common, most on '99 needles, ±black.
Vallecito Lake Dam	Mostly missing			Lots of mistletoe, some trees with heavy sawfly on 2000 needles.	Few
Road 576	Some missing			Worse in uplands, esp. on S-facing slope, not at Animas River Valley toeslope.	Heavy black fruiting on '99 and less '98 needles.

Examining shoots to precisely determine needle retention and discoloration by year was difficult on large trees because only lower branches were accessible, if those. Therefore, detailed examination of shoots of larger trees was based on branches that may have been of lower than average vigor.

These brief observations suggested that:

- Discoloration was severe,
- Young, photosynthetically important foliage was affected (in some cases even 2000 needles),
- Abnormal loss of needles was occurring,
- A needle-cast pathogen was associated with the damage, and
- Poor needle retention was leading to thin crowns.

3.1.1 Formal Field Sampling

Among 108 trees studied on 36 sites, mean years of needle retention was 2.4. Most trees had 3 or fewer years of needles; only one tree held five years of needles (Table 2).

Table 2. Years of needle retention of trees examined in early summer 2001. Retention of needles produced in 2000 is considered one year of retention and so on to 1996 (5 years retention).

Years of retention	No. of trees
1	13
2	44
3	41
4	9
5	1

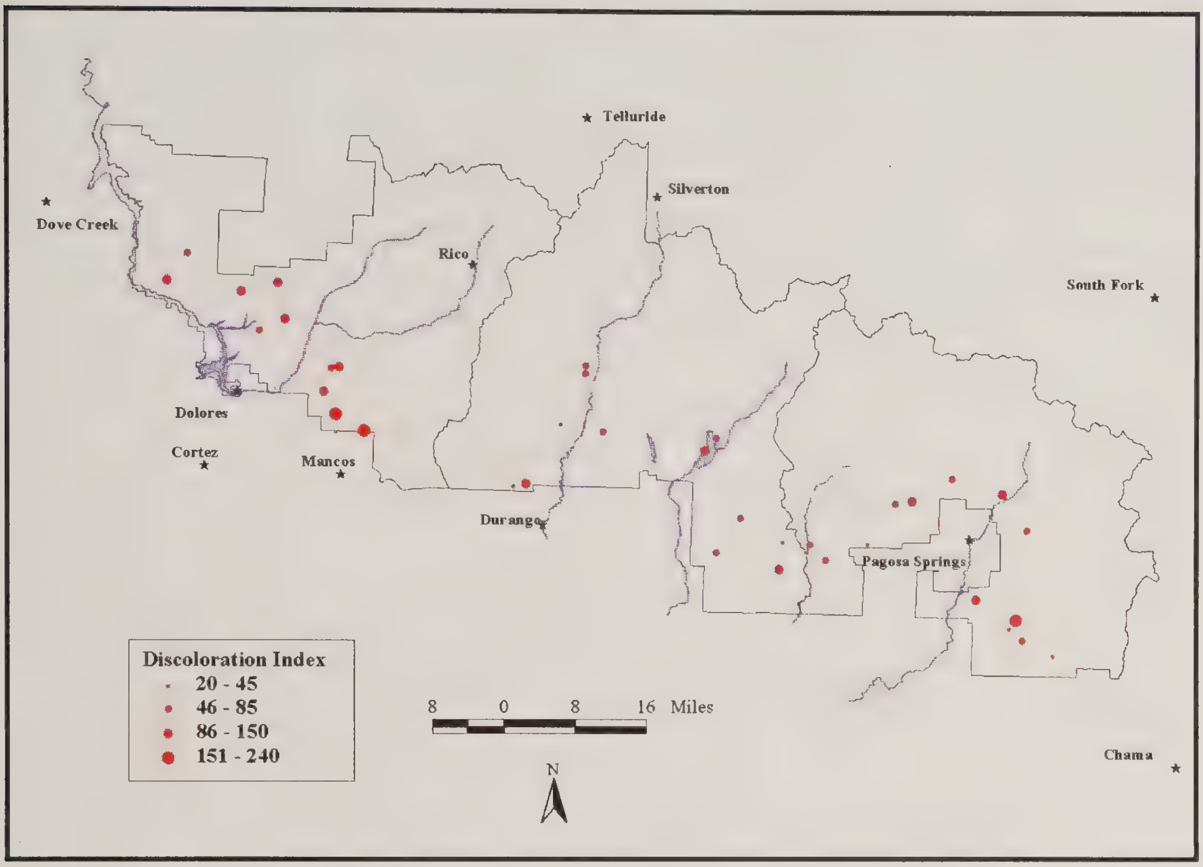

Figure 2. Discoloration index measured at sample sites on the San Juan National Forest.

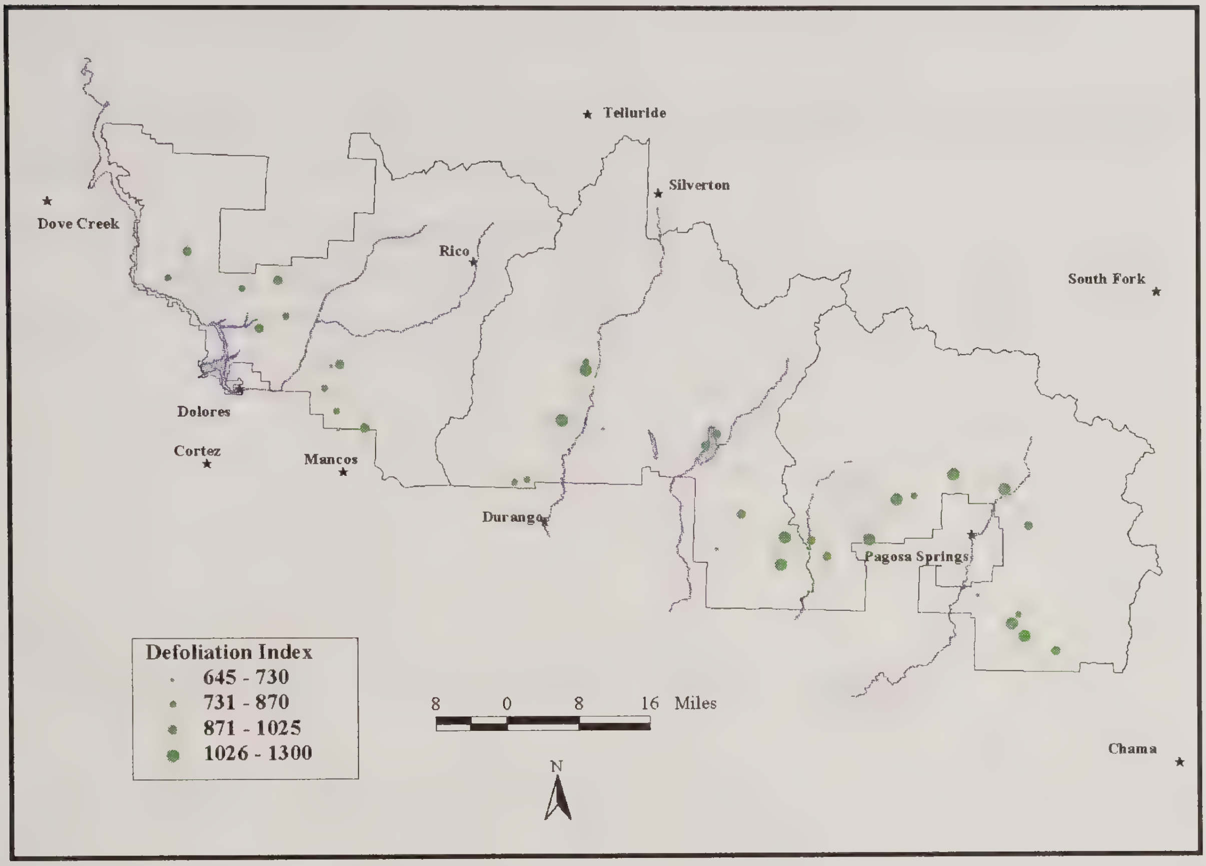

Figure 3. Defoliation index measured at sites on the San Juan National Forest.

Discoloration index (Fig. 2) and defoliation index (Fig. 3) were high at sites scattered throughout the forest. However, there was a trend toward high discoloration index on the western end and high defoliation index on the eastern end of the Forest.

Correlations among continuous variables were mostly weak and/or nonsignificant (Table 3). The first three variables in the table are considered independent variables and should be compared primarily with the remaining, dependent variables.

Table 3. Matrix of correlation coefficients among continuous variables.

	Elevation	Slope %	Basal area	% pine affected	% shoots affected	Avg. disc. rating	Discolor. index	Defol. index
Elevation		-0.362[a]	0.033	0.315	0.320	0.212	0.140	-0.073
Slope %			0.084	-0.164	0.117	-0.118	-0.336	0.340
Basal area				-0.027	0.121	0.147	0.319	0.140
% pine affected					0.183	0.590	-0.062	-0.089
% shoots aff.						0.509	0.245	0.285
Avg. disc. rating							0.309	-0.160
Discolor. index								-0.367
Defol. index								

[a] Statistical significance is indicated by underline ($p<0.05$) and double underline ($p<0.01$).

The mean basal area (BA) among all sites was 96 ft^2/acre and ranged from 20-200 ft^2/acre. Basal area was positively correlated with both discoloration index and defoliation index but those relationships were weak and not significant. Sites with discoloration index greater than the median (77.5) had a mean BA of 109 ft^2/acre; sites with lower discoloration index had a mean BA of 84 ft^2/acre (difference not significant).

Sites with complete aspect and defoliation data were separated into a low-defoliation group (defoliation index ≤930, the median) and a high-defoliation group (defoliation index >930). Results (Table 4) suggested that the high-defoliation sites tended to have a southern aspect and the low-defoliation sites had a more western aspect. The differences in mean angle were more pronounced when angular mean was weighted by percent slope. Variances (which range from 0, no variability, to 1, maximum variability) were fairly high for all calculations.

Table 4. Differences in aspect between sites with low defoliation (defoliation index ≤930, the median) and high defoliation, with and without weighting aspect by percent slope.

		Defol. index ≤median (n=16)	Defol. index >median (n=15)
Unweighted	Mean aspect	234°	184°
	Circular variance	0.64	0.63
Weighted by % slope	Mean aspect	258°	183°
	Circular variance	0.74	0.65

Needle cast was recorded (in some cases tentatively) in field notes on 25 of the 36 sites. In laboratory examinations of needles collected from those sites, we confirmed the presence of needle cast in only 11 of the 25 sites. The presence or absence of needle cast (as determined by laboratory examination, not by field notes) was not related to measures of damage except to discoloration index. Although needle cast was expected to lead to greater discoloration, sites with confirmed

[illegible] high [illegible] scattered through [illegible] around high deterioration index [illegible] the [illegible] end [illegible] index [illegible] end of the forest.

[illegible] among continuous variables were mostly [illegible] not significant (Table [illegible]) [illegible] variable [illegible] independent [illegible] should be [illegible] with the remaining dependent variables.

[illegible] correlation coefficients among [illegible] variables.

[illegible]	Slope	[illegible]	[illegible]	[illegible]	[illegible]	Deterioration index	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

The mean basal area (BA) among all sites was [illegible] ft²/acre and ranged from [illegible] was positively correlated with [illegible] and deterioration index [illegible] were weak [illegible] deterioration index greater than the median [illegible] had a mean BA of 109 ft² [illegible] with lower deterioration [illegible] had a mean [illegible] difference [illegible] significant.

Sites with complete aspect and [illegible] low-deterioration [illegible] index 59.0, the maximum [illegible] group [illegible] index [illegible] (Table 4) [illegible] sites tended to have a southern aspect and [illegible] sites had a more western aspect. The differences in [illegible] angle were more [illegible] when [illegible] compared [illegible] aspect. Variances [illegible] range [illegible] to 1, maximum [illegible] were fairly high for all [illegible].

[illegible] aspect [illegible] deterioration [illegible]

[illegible] the 80 sites, [illegible]
[illegible] [illegible] determined by [illegible]

needle cast had a lower mean discoloration index (57 ±10.5) than sites without confirmed needle cast (99 ±9.8; p = 0.015).

Moisture-holding capacity was classified in field observations as good, moderate or poor. Most sites (29) were rated as good, 7 as moderate, and none were rated poor. The only damage variable that was significantly different between good and moderate sites was average percent shoots affected (average overall estimate of the three sample trees), but again the relation was the reverse of expected. Good sites had 79 ±1.9% of shoots affected, moderate sites 64 ±10.8% (p=0.023).

Slope position showed a significant and meaningful relationship to both discoloration index and defoliation index. Although there were only 6 sites on upper slopes, they had significantly higher mean defoliation index than did hilltops, flats and lower slopes (Figure 4). In the case of discoloration index, the trend among slope positions was reversed. The overall analysis of variance for discoloration index was marginal but not significant (p=0.054). Subsequent multiple comparisons showed that hilltops had significantly greater discoloration than upper-, mid- and lower-slope positions, and flats also had greater discoloration than upper slopes.

Similarly, sites with high defoliation index (>930, the median) were on steeper slopes than other sites (not significant) and sites with high discoloration index (>77.5, the median) were on significantly less steep slopes (p=0.011).

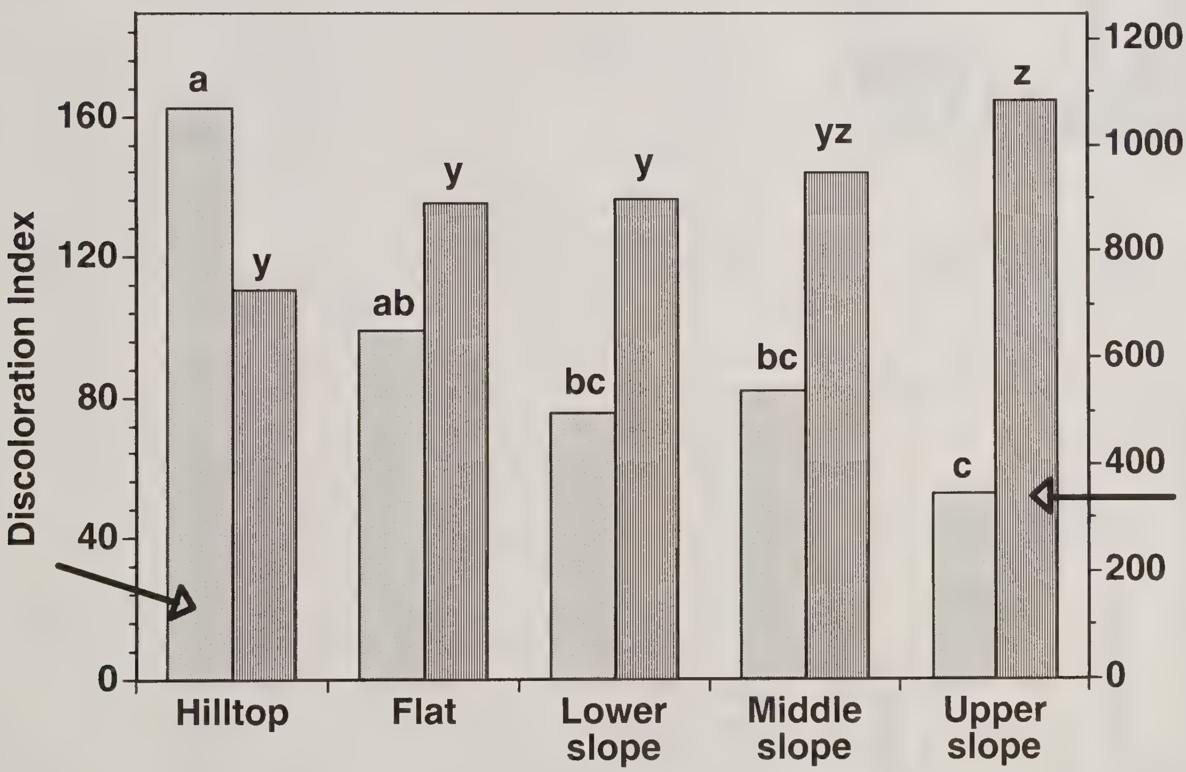

Figure 4. Comparison of mean defoliation index and mean discoloration index among slope positions. Within a series, means without a letter in common are significantly different (p = 0.05) according to Fisher's Protected Least Significant Difference test.

Neither growth rate nor growth decline correlated significantly with any discoloration or defoliation variable. However, growth rate, especially the recent 5-year growth rate, was significantly correlated with elevation (for the 5-year growth rate the correlation coefficient, r, was 0.62, p<0.0001; for the previous 15 years r=0.56, p=0.0006).

Considering all 34 sites for which growth data are available, there was an average growth decline of 17% in the last five years compared to the previous 15 years. The range among sites was 73% decline to 59% increase. Growth decline was negatively correlated with elevation (r=-0.39, p=0.024). In other words, ponderosa pine generally tends to grow faster at higher elevations, and trees at lower elevations suffered a greater growth decline in the last five years than trees at higher elevations.

3.2 Climate

Most of summer 1999 was quite wet throughout the central and southern mountains of Colorado, due in part to unusually strong monsoons in the area. The San Juan National Forest experienced what was probably one of the wettest summers on record (Figs. 5, 6).

Beginning in September 1999 through September 2000, conditions in the larger basin from Cortez east through Pagosa Springs to the Continental Divide were drier than normal. The Standard Precipitation Index (SPI) was approximately –1 (indicating roughly 1 standard deviation below the mean) or less for the 3-, 6-, and 12-month periods ending September 2000 (Nolan Doesken, Atmospheric Sciences Climate Center, pers. comm.). The 6-month period had an SPI of about –1 in southwest Colorado while the area north of the San Juan Mountains was near 0 (normal). The 12-month SPI went as low as –1.7 around Mesa Verde (SPI values of –2 are roughly equivalent to a 100-year event).

In particular, the early growing season of 2000 was dry (Figs. 5-7). Over most of the area, April precipitation was less than ½ to ¼ of average. May was very dry, with mostly less than ¼ average precipitation. June and July were generally well below average for the area. Durango went from April 16 to June 7, a critical period for growth, with only one episode of precipitation totalling 0.19". In Pagosa Springs (Fig. 7), only two days had more than 0.1" precipitation during the entire months of April, May and the first half of June.

Coinciding with the dry growing season of 2000 were very high temperatures (Fig. 8-10). During April in Durango the daily maximum temperatures were as low as the long-term average maximum temperatures on only 3 days (Fig. 8). Seven days around May equalled or broke daily records in Durango (with temperatures up to 98 F on May 29 at Durango station 52441). At Vallecito Reservoir, high temperatures reached or exceeded records for 15 days in late April, May and early June (Fig. 9).

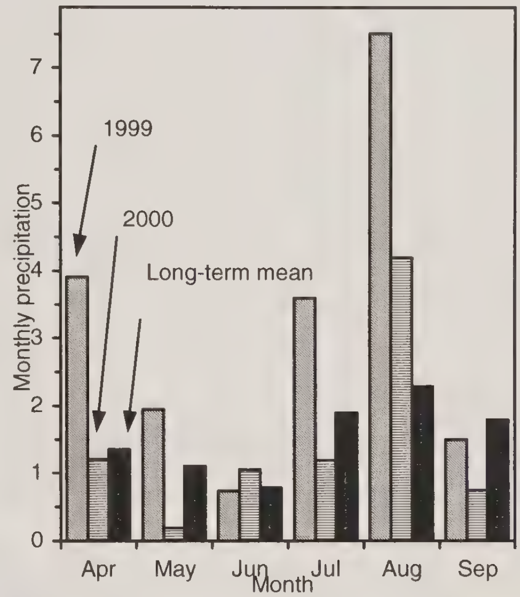

Figure 5. Precipitation in Durango during the growing seasons of 1999 and 2000 compared to long-term means.

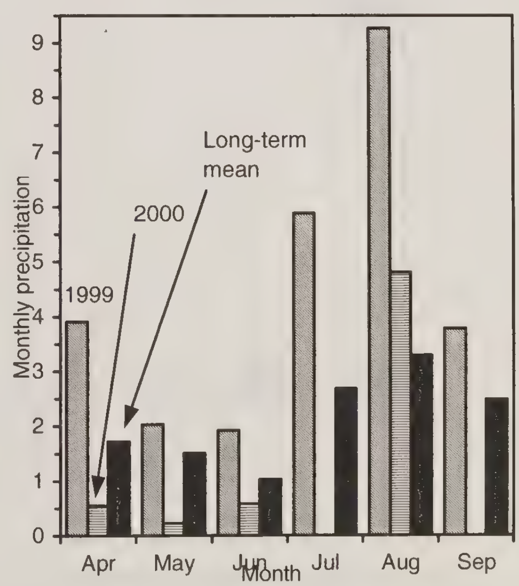

Figure 6. Precipitation at Vallecito Dam during the growing seasons of 1999 and 2000 compared to long-term means.

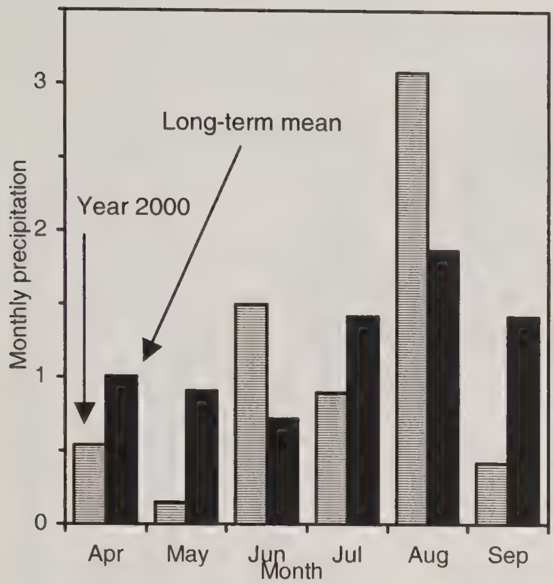

Figure 7. Precipitation in Pagosa Springs during the growing season of 2000 compared to long-term means. No records are available for 1999.

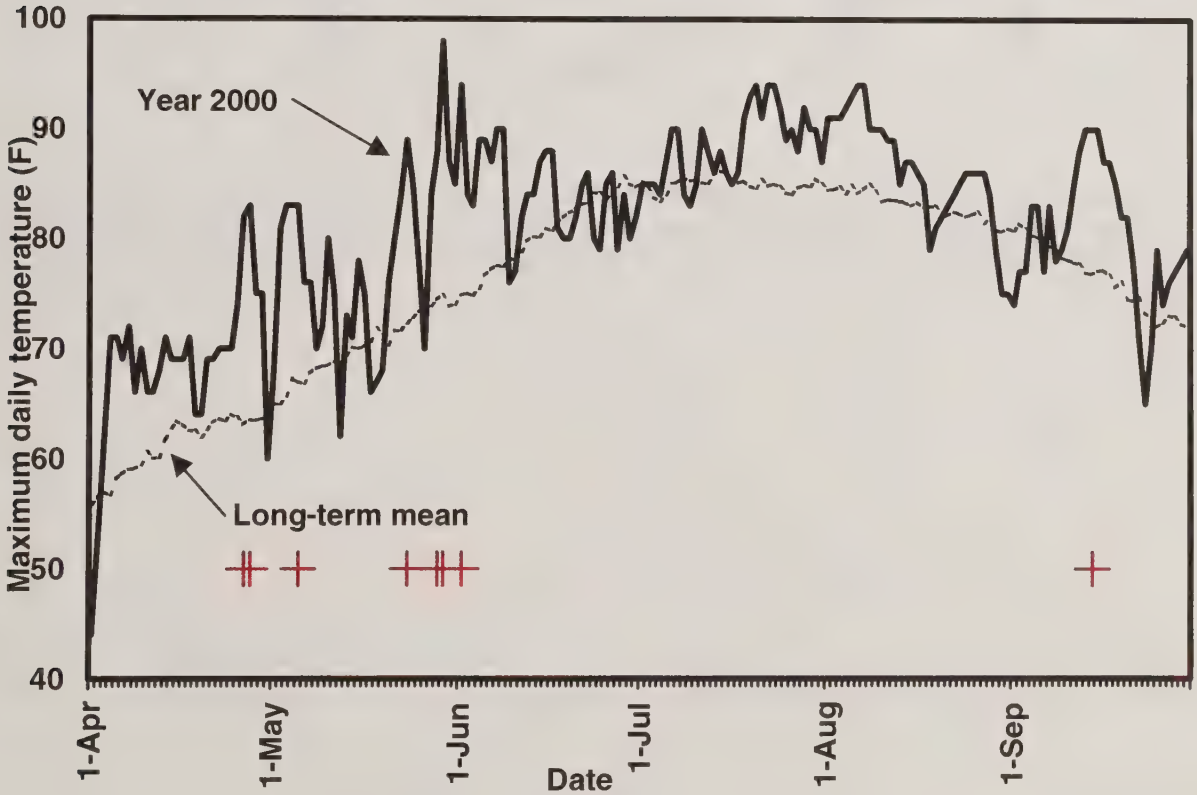

Figure 8. Maximum daily temperatures in Durango during the 2000 growing season compared to the long-term mean of maximum daily temperatures. The long-term mean is based on the years 1894-1991 at Durango station 52432. Year 2000 data are from Durango station 52441, which has been in operation only since 1991. Marks on the 50-degree line indicate days on which the record high temperature since 1894 was equalled or broken in 2000. Many more days were very close to record high temperatures.

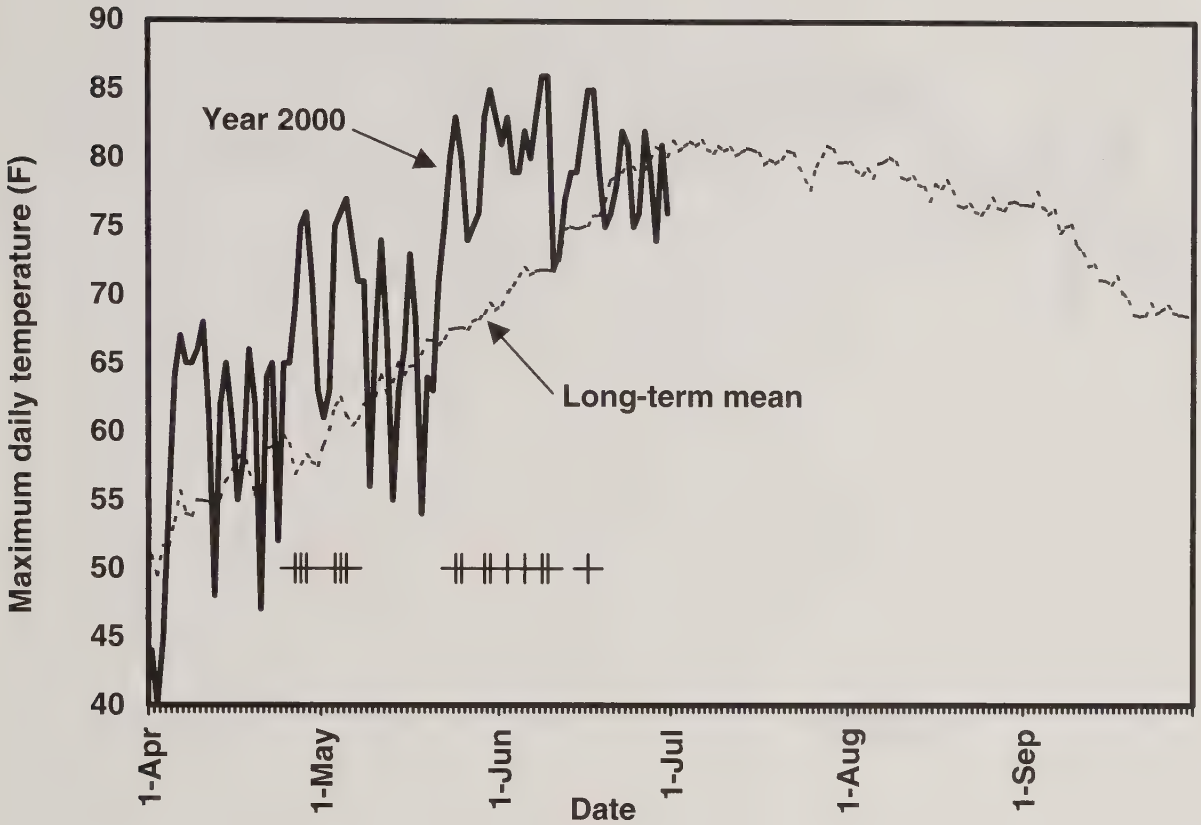

Figure 9. Maximum daily temperatures at Vallecito Dam during the 2000 growing season compared to the long-term mean of maximum daily temperatures. Records are missing after June 2000. The long-term mean is based on the years 1948-2000 at Vallecito Dam. Marks on the 50-degree line indicate days on which the record high temperature since 1948 was equalled or broken in 2000.

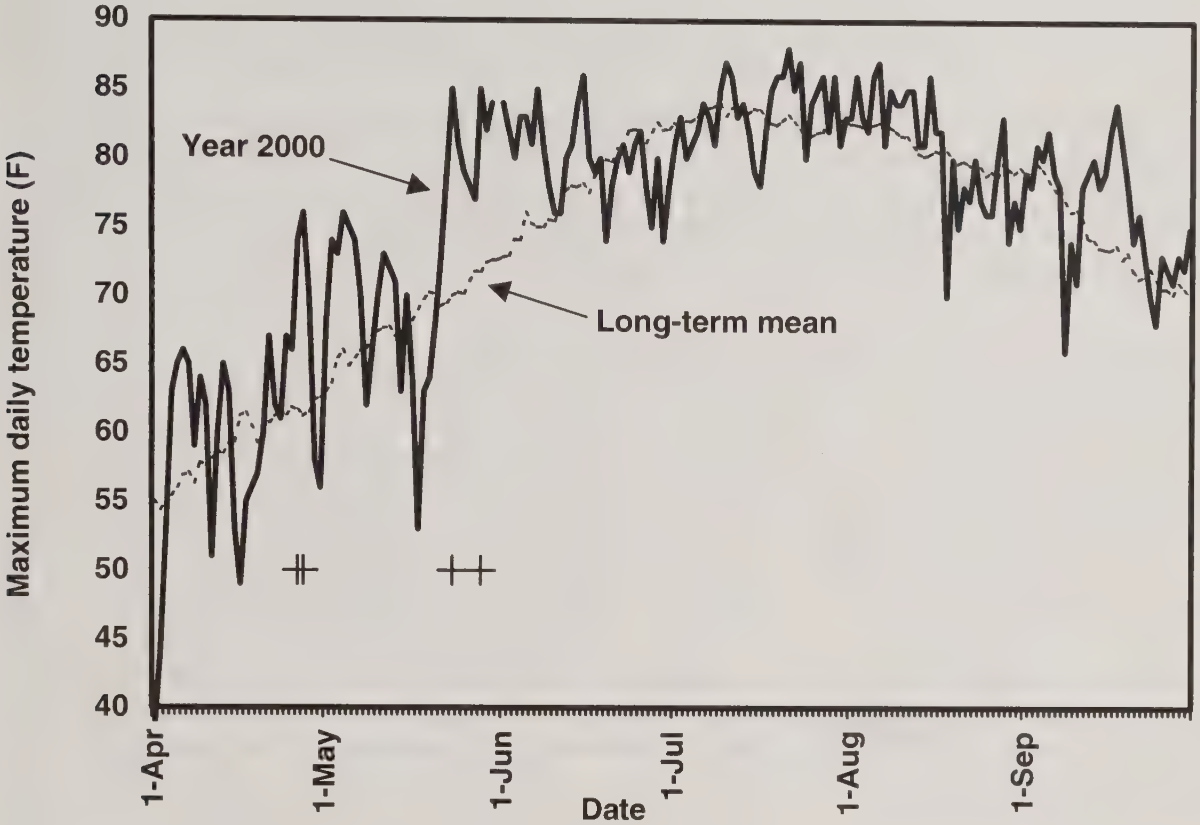

Figure 10. Maximum daily temperatures in Pagosa Springs during the 2000 growing season compared to the long-term mean of maximum daily temperatures. The long-term mean is based on the years 1906-1998 at Pagosa station 56258 (no records are available for 1999). Marks on the 50-degree line indicate days on which the record high temperature since 1906 was equalled or broken in 2000.

4. DISCUSSION

4.1 The Needle Cast

Needle-cast fungi infect living needles of conifers and often cause premature needle loss (needle cast). They reproduce and cause one episode of needle cast in a year (although, as discussed below, a generation may last up to five years). Spores are shot into the air during wet weather. The long, narrow shape and sticky sheath of spores increase the likelihood of intercepting and sticking to a moist needle. Symptoms usually do not appear during the year of infection and in some cases may not appear in the second year.

Damage by needle-cast fungi typically varies with weather conditions. During the time of year when fruiting bodies are mature and needles are susceptible, a period of continued leaf wetness and appropriate temperature must occur to allow opening of hysterothecia, dispersal of spores, and germination and penetration by spores on new foliage. These factors have not been adequately studied with this disease, but 6-18 hours of continued leaf wetness with temperatures around 70 F would be typical. If temperatures are much below this a longer period of leaf wetness is required and if it is much warmer the fungus may not be able to function. In addition, there is some indica-

tion that development of hysterothecia may be inhibited by warm weather in spring and early summer (Staley 1978). In part because of these requirements, it is very unusual for a severe epidemic of a native needle cast to be sustained for more than a few years in a row.

However, a common misconception is that these diseases require high amounts of rainfall for infection. The amount of rain is not important. If there is a sufficiently long period, e.g. 12 hours, of overcast with light drizzle or fog at the right time, there can be heavy infection in a very dry year. At all other times the fungus is protected from drying by needle tissue. Most weather records are not detailed enough to identify suitable infection periods accurately, even if the required conditions are known.

Some needle casts infect needles during the growing season of their production and kill them by the time the following year's needles are produced. Other needle casts kill older foliage (e.g., 2-5 years old), but it is not clear when infection occurs in that case. This is the pattern followed by *Davisomycella* species. A study by Staley (1978) of *Davisomycella* sp. (probably an undescribed species) sheds light on the timing of infection. He took branches from a tree with consistent, heavy infection in March 1966 and grafted them onto seedlings in the greenhouse far from any source of infection. He stripped off all needles but the 1965 needles. In 1966 there was no fruiting. In 1967, there was killing of and fruiting on a portion of the 1965 foliage. That year and every subsequent year he removed the needles with fruiting before it become mature. In 1968 and 1969, killing and fruiting occurred on successive portions of the 1965 foliage. No symptoms or fruiting occurred on foliage other than 1965. This experiment demonstrated that the fungus infected needles during the year in which they were produced and then underwent a latent period of 2-5 years before fruiting and killing the needles. Staley (1978) refers to unpublished inoculations suggesting that needles can also be infected by *Davisomycella ponderosae* during the year after their production, but such needles are apparently less susceptible than current-year needles.

Very little is known of the ecology of *Davisomycella ponderosae*. It is surprising that a fungus with such obvious fruiting bodies was not described until 1964 (Staley 1964a). Staley wondered why the fungus had not been described already, but speculated that either it had a narrow distribution or fruited rarely. At that time it was found on the Roosevelt, Pike and San Isabel National Forests along the Front Range of Colorado. It was found primarily on trees less than 30 feet tall and was in the lower crown of trees taller than 12 feet. In late July 1963, fruiting was found on needles produced in 1958-1961 (i.e., on needles older than the previous year's needles). The peak of maturity, and presumably sporulation, was between mid-July and mid-August. This could occur somewhat earlier on the San Juan N.F.

In late June of 1999, the fungus was found for the first time in Montana, in Fergus County in the central part of the state (McConnell 2000). On affected trees, 1998 needles were browning from the tips and 1997 needles were completely faded to straw-brown. Damage was greatest in small trees and in the lower crowns of large trees. Fruiting was seen on the faded 2-year-old needles. Although the disease was strikingly apparent in June and even July, by August many of the older affected needles had been shed and the trees appeared green and healthy from a distance.

4.2 Climate

The very wet summer of 1999 was followed by much drier conditions and a very hot summer of 2000. Considering both precipitation and temperature, the year 2000 appears to represent a severe drought for the San Juan National Forest as a whole, particularly early in the growing season. Temperatures appear to have been most extreme toward the western part of the Forest, but this is based on an incomplete analysis of weather records.

4.3 Symptoms and Stand/Site Factors

We do not have statistical data for "normal" needle retention in ponderosa pine in this area to determine if the retention that we observed (Table 2) significantly deviates from normal. Certainly most trees are at the low end or below what is generally considered healthy for ponderosa pine. Published data on normal needle retention for *Pinus ponderosa* var. *scopulorum*, the variety in the Rocky Mountains, is very limited. Needles of the species overall are said to be retained (2-)4-6(-7) years (Morin et al. 1993). In the intermountain region, needles of ponderosa pine (probably *P. p.* var. *scopulorum*) are said to persist for "less than 5 years" (Cronquist et al. 1972). Normal needle retention in Jeffrey pine is 5-6 years (Patterson and Rundel 1995). In ponderosa pine in California, 5 years' needle retention is considered healthy (Munz and Keck 1973), and this is the standard that is often used to evaluate ozone damage in ponderosa pine (Miller et al. 1995). Of the 108 trees examined for our intensive field study, only one held needles 5 years old (produced in 1996).

The cause of differences in damage indicators (defoliation index and discoloration index) among slope positions is not clear. The two indicators had reverse trends among the slope positions. It may be that the damage occurred irrespective of slope position, but that it progressed more quickly on slopes (where drought effects would be greater). In this interpretation, damaged needles had already been largely cast on middle and upper slopes, while discoloration was still the dominant form of damage on hilltops and flats.

Elevation was not strongly related to damage, although there was a tendency toward higher discoloration rating and a greater percentage of shoots and trees affected at higher elevations.

Basal area generally showed positive relationships to damage, but none of the relationships were significant. This included correlations of basal area to damage indicators (especially discoloration index) and comparisons of mean basal area between sites classed by high vs. low damage (separated at the median). Basal area is discussed further in section 4.5, Outlook.

4.4 Cause of the Damage

Is the discoloration and defoliation on the San Juan N.F. a result of the needle-cast fungus, the drought, or some combination of the two? Needle casts, including *Davisomycella ponderosae*, typically are more severe on small trees and lower crowns of large trees (Staley 1964a), but observations suggest that the damage on the San Juan is on all sizes of trees and throughout the crowns. This suggests that the San Juan is experiencing an unusually severe outbreak of needle cast or another factor is contributing to the damage. Because damage by a related fungus, *D. medusa*, is increased by drought (Wagener 1959), it is reasonable to suspect that the same may be true of *D. ponderosae*.

A likely scenario is that the wet years preceding the drought led to an increase in fungal populations, even in upper crowns and large trees. Although the epidemiology of these fungi is not fully understood, needles may be infected during the year of their production, after which the disease becomes dormant (latent infection; see section 4.1). A drought could then permit the fungus to develop and kill more infected needles than it otherwise might (Staley, personal communication). In the Dolores River area, where the problem was observed even before 1999, similar local weather patterns on a smaller scale may have allowed populations to build up earlier.

In the preliminary observations, we found some needle-cast fruiting at every site we visited, although it was rare in some cases. Because the occurrence of fruiting in the second, more intensively sampled set of field sites is uncertain, we did not place much emphasis on those in data

[illegible] Site Factors

[illegible] do not have statistical data [illegible] of normal needle retention [illegible] the area [illegible] if the retention that we observed [illegible] significantly [illegible] normal. Certainly [illegible] trees are at the low end [illegible] what is [illegible] published data on normal needle retention [illegible] is very limited. Measures of the [illegible] et al. 1993). In the intermountain region [illegible] ponderosa pine [illegible] and is persistent less than [illegible] (1972) found needle [illegible] Jeffrey pine [illegible] 5 to 6 years [illegible] and [illegible] pine [illegible] California [illegible] is considered healthy (Miller and Keck 1973) [illegible] ozone damage to ponderosa pine [illegible] Miller [illegible] (1996) [illegible] trees [illegible] only [illegible] held needles [illegible] years old [illegible]

[illegible] of differences in damage [illegible] and discoloration [illegible] positions [illegible] It may be that the damage occurred [illegible] slope [illegible] on slopes [illegible] interpretation, damage [illegible] been [illegible] of middle and upper [illegible] discoloration [illegible] of discolor[illegible] [illegible]

[illegible] was not strongly related to [illegible] although [illegible] tendency [illegible] highest [illegible] rating and greater [illegible]

[illegible] generally showed positive [illegible] to damage, but [illegible] the relation [illegible] [illegible] included correlation [illegible] to damage [illegible] and conifer [illegible] by [illegible] damage [illegible] at the median). [illegible]

Cause of the Damage

[illegible] discoloration [illegible] on the San Juan NF [illegible] fungus, the [illegible] or some combination of the two? Needle casts including *Dothistroma* [illegible] are more [illegible] small trees and [illegible] crowns of large trees (Staley 1964), but [illegible] that the damage [illegible] the San Juan [illegible] of trees and throughout the crowns [illegible] that the San Juan is experiencing an unusually [illegible] outbreak of needle cast [illegible] contributing to the [illegible] Because damage by a related fungus [illegible] (Weir [illegible] 1919), it is reasonable to suspect that the same may be true [illegible]

[illegible] is that the wet years preceding the drought [illegible] to an increase [illegible] upper crowns and large trees. Although the epidemiology of these fungi [illegible] be infected during the year of their production, after which the disease [illegible] latent infec[illegible] see section 4.1). A drought could then permit the fungus to [illegible] needles than it otherwise might (Staley, personal communication). [illegible] the problem we observed, even before 1996, similar local weather [illegible] have allowed populations to build up earlier.

[illegible] observations [illegible] found some needles [illegible] fruiting at every site we visited, [illegible] occurrence of fruiting [illegible] second, [illegible]

analysis and interpretation. The drought could account for the low proportion of discolored and dehiscing needles that have fruiting in some cases.

4.5 Outlook

Because conifers depend on multiple years of foliage and cannot replace foliage as many hardwoods can, conifers are generally more sensitive to foliage loss than are hardwoods. Defoliation generally causes growth loss in proportion to the degree of defoliation (Church 1949). Because the visible discoloration represents an abnormal loss of foliage, a decrease in growth can be expected and may be represented in the decline measured on some of the sites in this study. However, needle cast of this sort (killing from the older end of the needle-age spectrum) is generally considered less damaging than repeated years of needle cast by fungi that attack and kill the most recently formed foliage.

Depending on other factors and future weather conditions, some trees with only one or two years of needle retention may die. This is especially likely if weather conditions facilitate continued needle-cast development or pine bark beetles develop high populations due to stressed trees.

Basal area has not been studied as a factor in management of needle casts. In this study, sites with higher basal area tended to have more discoloration, but no such relationship was significant. It seems likely, however, that basal area could play a role in this disease. All else being equal, it is known that overly dense, even-aged stands of conifers are more heavily impacted by needle cast than more open, uneven-aged stands, probably because of microclimate effects on leaf wetness periods for sporulation and infection. However, there may be an additional effect in this case, where drought stress appears to be involved. Trees in more open stands will probably be less stressed by drought, and thus have longer latent periods for any needle infections, than trees in denser stands. The needles would be retained and live longer. Basal area reduction, through thinning and/or fire, could therefore reduce the impact of future epidemics as well as reducing the likelihood of subsequent outbreaks of mountain pine beetle.

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[illegible] and [illegible] The [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] needle[illegible], that [illegible] [illegible].

Outlook

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[illegible] area has not been [illegible] [illegible] [illegible] [illegible] [illegible] higher than [illegible] tended to have [illegible] discoloration but [illegible] [illegible] [illegible] likely, however, [illegible] [illegible] [illegible] play a role in this [illegible] [illegible] [illegible] that overly dense, even-aged stands of conifers are [illegible] [illegible] [illegible] more open, uneven-aged stands, [illegible] by harvest of [illegible] or [illegible] [illegible] for [illegible] and [illegible]. However, there may [illegible] an additional [illegible] [illegible] [illegible] [illegible] [illegible] to be involved. [illegible] in more [illegible] [illegible] [illegible] by drought [illegible] thus have [illegible] [illegible] [illegible] for [illegible] needle infection [illegible] [illegible] stands. The needles would [illegible] and [illegible] longer. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] the [illegible] of the [illegible] [illegible] [illegible] [illegible] of [illegible] [illegible] of mountain pine beetle.

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[illegible] Steve [illegible], [illegible] Dave Crawford, Tom [illegible], Phil [illegible], [illegible] Tim [illegible] for [illegible] samples and [illegible] field observations. [illegible] [illegible] collected [illegible] the field data. John Staley [illegible] [illegible] [illegible] useful advice about needle casts. Nolan Donaker, [illegible] and Roy Mask [illegible] and [illegible] of the manuscript.

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6. APPENDIX A – SUGGESTED PROTOCOL FOR FIELD SAMPLING

This sampling is designed to get general information on the discoloration and to provide information on two potential causes, needle cast and drought. To determine factors associated with the problem, it will be necessary to take data in areas representing the entire range of discoloration, including areas that have no or minimal discoloration.

6.1 Selecting sites/stands

To make this most efficient, the judgment of the field crew will be important. I suggest something like the following. First, outline general areas on the Forest where ponderosa pine is a major species. If it is estimated that 5 field days can be allotted to the actual survey, divide this ponderosa pine area into 5 roughly similar-sized areas, each to be surveyed in about a day's time. Either in the office beforehand or in the field, identify several forest roads that travel through major, diverse portions of that day's pine area. Distribute approximately equidistantly the number of points that you can sample in a day along those roads.

It is important not to be locked into those points. If any is unsuitable for any reason (no ponderosa pine, development, obviously abnormal), skip it and choose another as appropriate. Also, it is important to sample sites with full range of discoloration. Therefore, if you pass a stand that is relatively free of discoloration in a large area of discoloration, or vice versa, please make every effort to sample that anomalous stand.

When you decide to use a particular site in the field, number each site in serial order and write a brief description of the location on the form (see below). Also record the location by number on a Forest map with an indelible marker.

After pulling off the road, you then must select an actual point to begin taking data. [Steve, please put your ideas on that here – something like walking around to choose an area of representative density, going a chain in or whatever].

6.2 Basic site/stand features

Record elevation, which if necessary can be estimated from BLM maps later. Record aspect, the compass azimuth that you face when you have the hill at your back and the lower slope is in front of you. Slope% can be read with a clinometer. Slope position can be noted as follows:

Slope position: flat (near no slope) FL
- hilltop/ridge HT
- upper slope/shoulder US
- midslope/backslope MS
- lower slope/footslopeLS
- valley/toeslope VA

We may try to use a soil survey map to obtain moisture-holding capacity (MHC) of the soil in the general area, but in case that is too locally variable for the scale of those maps, visually classify soil moisture-holding capacity by appearance after digging 6 inches or so as follows:

– poor: coarse, sandy/rocky, little organic matter
– moderate
– good: fine-grained, clay loam, organic matter

Use a 20-basal area factor prism at the sample point and count the number of trees in. Record the presence of any other tree species, including major shrubs like Gambel oak (these may give clues about general moisture conditions of the site).

6.3 Discoloration and foliage features

Looking around the stand in general (not restricting to prism plot trees), estimate the percentage of trees that show the discoloration. Then describe the pattern/distribution of discoloration within the crowns. You may find that it is uniformly distributed in the crowns, or it could be concentrated in the lower or upper crown.

Then choose three trees for more detailed observations. The simplest approach would be to choose the three trees closest to your plot center, but if some are not representative for some reason you may skip them. It is OK to use small trees (say, as small as 6 feet) if they are represented in the understory. But if the three closest trees are all small or all large and there is clearly another component to the stand that is not represented, pick another tree that represents it.

For each tree estimate roughly the percentage of shoots (i.e., anything with an apical meristem, back to where it meets a live branch) that show any discoloration. There are thousands of shoots on a mature tree, so just estimate. Then, also give each tree a discoloration rating to rate the general intensity/amount of discoloration. Use a 5-point scale as follows:

0 no discoloration

1 low discoloration

2 moderately low

3 moderately high

4 high amount of discoloration

From each tree, cut three shoots that appear to be reasonably dominant (at the branch level) and vigorous (in other words, don't select shoots that are being shaded out). In larger trees, a pole pruner may be necessary and even then you will be restricted to lower branches.

Determine where the annual bud scars are on the shoots and identify in what year each rank of needles was produced. For the following, consolidate your observations of the three shoots into one set of data on the form for each tree (if the shoots differ greatly, record a rough average). For years 2000 and earlier, indicate needle retention on the form. I will assume that an X or check mark means they are essentially all there (100%) for that year, and that a blank means they are essentially all gone. For partial presence, indicate by a rough percentage (even 10's only) what portion are still there. Then do the same for discoloration. A blank will mean no discoloration (either because the needles are all green or all gone!); otherwise estimate percent discoloration of the retained needle tissue in that year (even 10's).

6.4 Needle cast

Using the samples I sent as a guide, look for fruiting of needle-cast fungi. Do not restrict yourself to the cut shoots or even to the 3 sample trees. If any is found, record the needle year it was found in and estimate, for the site, the *percentage of discolored needles of that year that have any*

fruiting at all. Take samples of the fruiting needles and put them in a letter-size envelope labelled with the site number and needle year (the more the merrier; you can stuff the envelope if you want although a dozen needles or so should be more than enough). If you find them on multiple years of needles, record the data separately (as a separate year and percentage) and put the samples in a separate envelope.

6.5 Comments:

Are the 2000 needles shorter than previous years' needles? This might be a useful indicator of severe spring drought stress. We saw that at some sites in our quick trip, and it is the kind of thing that should be noted in the comments. Anything noteworthy about annual shoot growth in certain years (the distance between annual bud scars on the shoot, which you can identify to year)? Do trees in the area appear to be thin-crowned, or have lion's-tailing (needles seem to be clumped at the end of bare branches)? Any other observations that might be pertinent? Please record them.